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COMPUTER PROGRAM FOR CALCULATION OF AIRFOIL PRESSURE AND TURBUL--ETC(U)
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COMPUTER PROGRAM FOR CALCULATION OF AIRFOIL PRESSURE AND TURBULENT FRICTION DRAG

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A computer program has been developed which calculates approximate pressure drag coefficient values of thin symmetrical airfoil sections based on convex airfoil data. Flat plate turbulent friction results are also included for fully developed turbulent flow.

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S U M M A R Y

This report documents the method which was developed during the creation of a computer program to calculate thin symmetrical airfoil pressure and turbulent friction drag.

The computer code was written by the NAVAIRDEVCEN to provide a consistent method for the determination of empennage form drag of high performance aircraft.

The program and supporting subroutines are written in FORTRAN for use on a CDC 6600 computer. The appendices of this report include a sample problem input/output listings, computer program listing and a program user's guide of the method.

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LIST OF FIGURES

LIST OF SYMBOLS

Symbols	Description	Dimension
c	Airfoil chord	(m or ft)
c_d	Section pressure drag coefficient, $\frac{D}{\frac{\rho}{2} U_\infty^2 c}$	
$\tilde{c}_d$	Section pressure drag similarity coordinate	(m or ft)
c_f	Compressible turbulent friction drag coefficient	
c_{f_i}	Incompressible turbulent friction drag coefficient	
c_p	Pressure coefficient, $\frac{p - p_\infty}{\frac{\rho}{2} U_\infty^2}$	
$d\ ()$	Derivative parameter	
D	Pressure or friction drag	(N or LBF)
M_∞	Free-stream mach number	
p	Airfoil surface pressure	(N/M^2 or LB/Ft^2)
p_∞	Free-stream static pressure	(N/M^2 or LB/Ft^2)
Re	Airfoil Reynold's number	
t	Airfoil maximum profile thickness	(m or ft)
U_∞	Free-stream velocity	(m/sec or ft/sec)
X,Z	Cartesian coordinates, where x extends in the direction of the free-stream velocity	(m or ft)
γ	Ratio of specific heats, for air = 1.4	
ρ_∞	Free-stream density of air	(Kg/M^3 or LB/Ft^3)
τ	Airfoil thickness ratio, t/c	

INTRODUCTION

This report describes a two-dimensional linearized flow computer code which was derived by the NAVAIRDEVCEN and successfully utilized to calculate form drag estimates of thin symmetrical non-lifting airfoil sections. The computer code was developed during a NAVAIRSYSCOM sponsored Aft Fuselage Twin Nozzle Fighter-Type Aircraft Drag Project. The project involved the compilation of a large data base of aircraft geometric and flight performance variations associated with aft fuselage drag measurements of various wind tunnel fighter models.

One of the problems which was encountered in comparing the test data from the various sources was that some of the data included empennage drag contributions and some of the data included only the metric tail contribution of interference drag. In order to compare the data on a consistent basis, this computer method was developed to calculate form drag estimates of the horizontal and vertical tail surfaces for the wind tunnel models with metric empennage sections.

In general, the analysis can be extended to calculate two-dimensional linearized flow pressure drag and compressible fully developed turbulent friction drag of any thin symmetrical non-lifting airfoil section typical on high performance fighter aircraft.

A sample case is included in Appendix A, together with the resulting sample output. A listing of the main FORTRAN source program and the required subroutines are included in Appendix B.

DISCUSSION

This report describes a two-dimensional linearized flow computer method for pressure drag calculation of thin symmetrical non-lifting airfoil sections. The method approximates the drag characteristics using a symmetrical circular-arc airfoil in lieu of the actual airfoil section.

The transonic pressure drag coefficients of two-dimensional thin symmetric airfoil sections can be represented in the form of similarity parameters (see references (a) and (b)) which coalesce geometry variations into a unified function of characteristic similarity coordinates. The results of Spreiter (reference (a)) for the theoretical and experimental pressure drag of complete circular-arc airfoil sections are utilized as the characteristic similarity coordinate within the transonic linearized flow regime.

The transonic drag characteristics are extended into the subsonic linearized flow range by matching the Prandlt-Glauert drag expression (see reference c)) to the low range transonic similarity function The characteristic transonic similarity function has also been extended into the supersonic drag range by matching the two-dimensional symmetric circular-arc simple wave drag theory (see reference (d)) to the high transonic similarity function.

The matching in the above analysis yields a single characteristic function of pressure drag for thin two-dimensional symmetric circular-arc airfoil sections valid throughout the tri-sonic range. The characteristic function is presented in Figure 1, where the ordinate represents the similarity drag coefficient and the abscissa is represented by Spreiter's similarity coordinate. The utility of the characteristic function lies in the ability to compress the pressure drag results of various circular-arc profile configurations into a single function represented by similarity coordinates.

The tri-sonic circular-arc pressure drag characteristic has been programmed in terms of the similarity parameters. The computer program presented in this report interpolates the characteristic circular-arc pressure drag function using a mathematical spline computer routine for various input data values to yield the pressure drag coefficients.

A friction drag calculation is also performed within the computer program for fully developed turbulent flow across a flat plate flow model which approximates the thin airfoil profile surface. The friction drag coefficient is calculated using the compressible form of the Prandtl-Schlichting turbulent flat plate equation (see reference (e)).

The pressure and friction drag coefficients are combined into a total form drag coefficient which can be referenced from the section airfoil area to any other reference (i.e., wing reference area). The governing equations that were utilized in formulating the pressure and friction drag analysis are presented in the methodology section.

The assumptions which are inherent in the computer program associated with the derived form drag methodology can be summarized as follows:

1. Thin symmetrical two-dimensional airfoil pressure drag characteristics can be approximated with sufficient accuracy by an equivalent thin symmetrical circular arc airfoil.

2. The thin smmetrical circular-arc airfoil transonic pressure drag characteristics can be represented in similarity parameter coordinates.

3. The thin symmetrical circular-arc airfoil subsonic pressure drag coefficients can be represented by the Prandtl-Glauert expression in terms of similarity parameters matched to the transonic similarity coordinates.

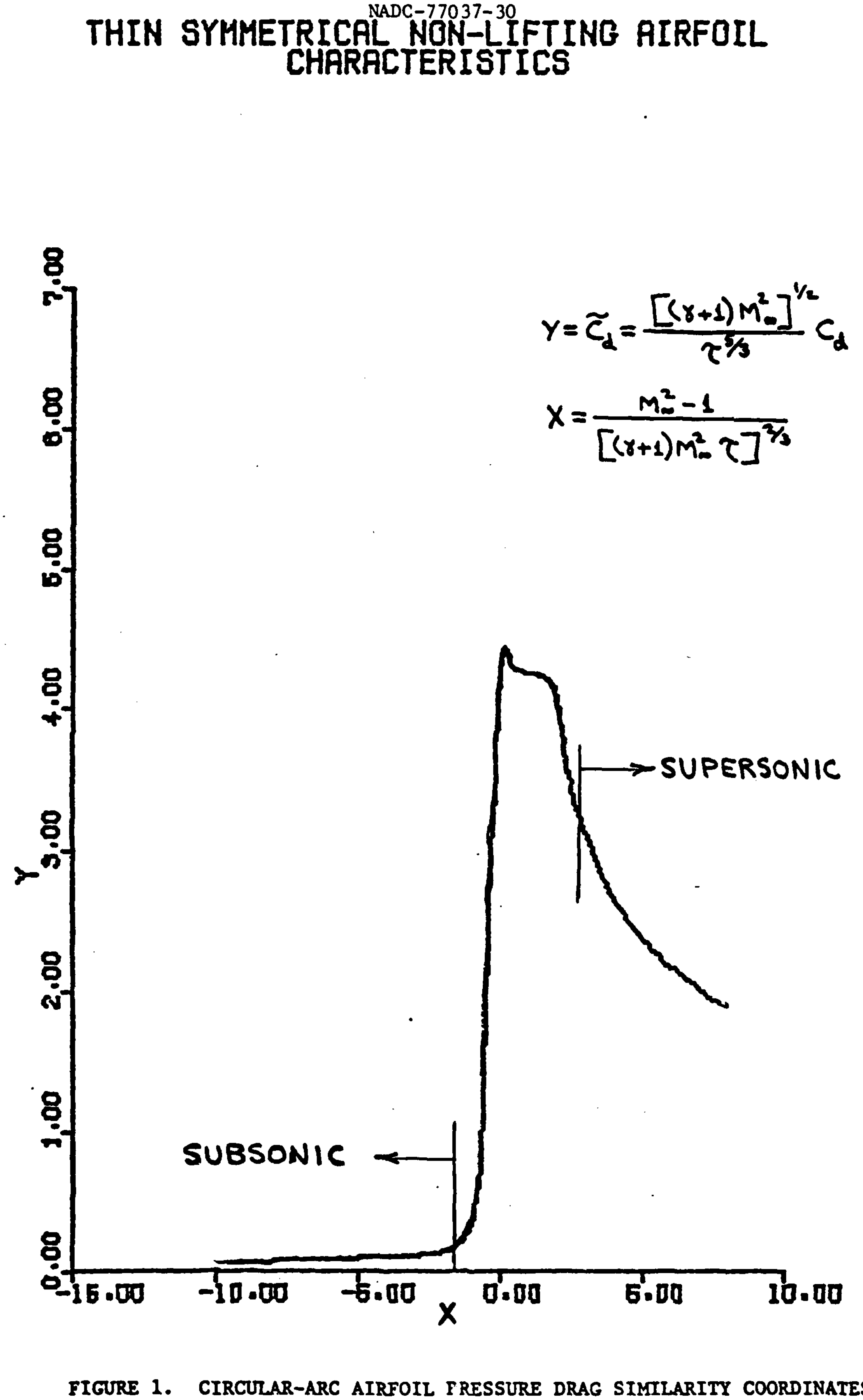

FIGURE 1. CIRCULAR-ARC AIRFOIL PRESSURE DRAG SIMILARITY COORDINATES

4. The thin symmetrical circular-arc airfoil supersonic pressure drag coefficients can be represented by a wave drag expression in terms of similarity parameters matched to the transonic similarity coordinates.

5. The thin symmetrical airfoil fully developed compressible turbulent friction drag characteristics can be approximated with sufficient accuracy by flat plate theory.

The computer method was applied during an Aft Fuselage Drag Prediction Analysis (reference (f)) to form the empennage drag estimates for several fighter aircraft configurations. The accuracy of the method for the thin symmetrical airfoils, from the above analysis, resulted in an error of less than ten drag counts. The demonstrated degree of precision is considered acceptable for most drag estimates of high performance aircraft.

METHODOLOGY

Biconvex Circular-Arc Airfoils

The thin airfoil section considered in the analysis of this report can be represented to sufficient accuracy by the following equation,

$$\frac{z}{c} \equiv 2\tau \left[\frac{x}{c} - \left(\frac{x}{c}\right)^2\right] \tag{1}$$

The theoretical and experimental pressure distribution on this type of airfoil surface has been investigated by Spreiter (reference (a)) for Mach numbers near unity and for various thickness ratios.

Pressure Drag Coefficients

The pressure drag coefficients are obtained from the known pressure distribution across the airfoil profile by the following equation,

$$c_d \equiv 2\int_0^1 c_p \frac{d\ (z/t)}{d\ (x/c)} \, d\left(\frac{x}{c}\right) \tag{2}$$

The following similarity transformation is defined for the transonic pressure drag coefficient,

$$\tilde{c} = \frac{\left[(\gamma + 1)\ M_\infty^2\right]^{\frac{1}{3}}}{\tau^{5/3}} \, c_d \tag{3}$$

The transformed drag coefficient has been experimentally related to airfoil geometry and stream flow conditions by the following functional relation,

$$\tilde{c} \equiv f\left(\frac{M_\infty^{\,2} - 1}{\tau^{2/3}\left[(\gamma + 1)\ M_\infty^{\,2}\right]^{2/3}}\right) \tag{4}$$

The above function has been defined by Spreiter for thin two-dimensional symmetric circular-arc airfoil sections valid throughout the transonic drag range and is presented in figure 1.

The subsonic pressure drag coefficient can be matched with the transonic coefficient. Taking the Prandtl-Glauert pressure drag expression (see reference (b)) in the following form,

$$c_d = \frac{0.0005}{\sqrt{1 - M_\infty^2}} \tag{5}$$

This coefficient is subjected to the same similarity transformation,

$$\tilde{c}_d = \frac{\left[(\gamma + 1)\ M_\infty^2\right]^{1/3}}{\tau^{5/3}} * \frac{0.0005}{\sqrt{1 - M_\infty^2}} \tag{6}$$

The transformed subsonic drag coefficient is presented in the labeled subsonic portion of figure 1.

Likewise the transformed transonic pressure drag coefficient can be matched with a supersonic drag coefficient. Using the following expression for supersonic wave drag (references (b) and (c)) for thin symmetric circular-arc airfoil sections,

$$c_d = \frac{16\tau^2}{3\sqrt{M_\infty^2 - 1}} \tag{7}$$

The transformed supersonic pressure drag coefficient is obtained in the following form,

$$\tilde{c}_d = \frac{\left[(\gamma + 1)\ M_\infty^2\right]^{1/3}}{\tau^{5/3}} * \frac{16\tau^2}{3\sqrt{M_\infty^2 - 1}} \tag{8}$$

This transformed drag coefficient is presented in the labeled supersonic portion of Figure 1.

Friction Drag Coefficients

Fully developed turbulent incompressible friction drag of a thin circular-arc airfoil can be approximated with sufficient accuracy by the flat plate flow model of Prandtl-Schlichting (see reference(d)) represented by the following equation,

$$c_{f_i} = \frac{.455}{(\log_{10} R_e)^{2.58}} \tag{10}$$

The compressibility effects can be accounted for by use of the following experimentally developed relationship (see reference (e)),

$$\frac{c_f}{c_{f_i}} = [1 + .18M_\infty^2]^{-.35} \tag{11}$$

Combining the compressibility equation with equation (10) produces the Prandtl-Schlichting fully developed compressible turbulent friction drag equation in the following form,

$$c_f = [1 + .18M_\infty^2]^{-.35} * \left[\frac{.455}{(\log_{10} R_e)^{2.58}}\right] \tag{12}$$

The thin symmetrical circular-arc airfoil pressure drag coefficient was combined with the compressible turbulent friction drag coefficient to establish a total form drag coefficient based on the airfoil profile surface area.

C O N C L U S I O N S

The computer program which is described in this report can be applied to analyze the drag characteristics of any thin symmetrical non-lifting airfoil section. The empennage of high performance aircraft represents a typical area for analysis using the method of this report.

The computer method has been used with success, for several years, at the NAVAIRDEVCEN to formulate the drag characteristics of horizontal and vertical aircraft tail surfaces.

REFERENCES

(a) Spreiter, John R., "Thin Airfoil Theory Based on Approximate Solution of the Transonic Flow Equation," NACA Report 1359.

(b) Liepmann, H. W., and Roshko, A., "Elements of Gas Dynamics," Wiley, 1967.

(c) Corning, Gerald, "Supersonic and Subsonic Airplane Design,' published by author, College Park, Maryland, 1964.

(d) Schlichting, Hermann, "Boundary Layer Theory," McGraw-Hill, 1962.

(e) Howarth, L., "Modern Developments in Fluid Dynamics-high Speed Flow," Oxford, 1964.

(f) Lee, K. W., and Franz, J. J., "An Aft End Drag Data Base and Prediction Technique For Twin Jet 'Fighter Type' Aircraft," Report No. NADC-77021-30.

APPENDIX A

SAMPLE INPUT/OUTPUT LISTING

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DESCRIPTION

The sample case presented in this section is representative of the engineering problems that can be analyzed using the thin airfoil form drag method. The example represents the vertical and horizontal airfoil sections from an F-17 empennage. The inputs include the free-stream mach number and specific heat ratio together with the airfoil reynolds number, thickness to chord ratio and the ratio of airfoil area to wing area.

The output values include the calculated form pressure drag, the turbulent friction drag and the total form drag referenced to the wing area.

```
SAMPLE CASE #1: VERTICAL TAIL - FORM DRAG COEFFICIENT
.5        1.4       8.1       .04       .1
.6        1.4       8.1       .035      .3
.7        1.4       8.1       .03       .5
.8        1.4       8.1       .025      .7
.9        1.4       8.1       .02       1.
1.        1.4       6.0       .04       .1
1.1       1.4       6.0       .035      .3
1.2       1.4       6.0       .03       .5
1.3       1.4       6.0       .025      .7
1.4       1.4       6.0       .02       1.
1.5       1.4       4.9       .04       .1
1.6       1.4       4.9       .035      .3
1.7       1.4       4.9       .03       .5
1.8       1.4       4.9       .025      .7
1.9       1.4       4.9       .02       1.
2.        1.4       3.5       .04       .1
2.1       1.4       3.5       .035      .3
2.2       1.4       3.5       .03       .5
2.3       1.4       3.5       .025      .7
2.4       1.4       3.5       .02       1.
2.5       1.4       2.        .04       .1
2.6       1.4       2.        .035      .3
2.7       1.4       2.        .03       .5
2.8       1.4       2.        .025      .7
2.9       1.4       2.        .02       1.
999
F-17 HORIZONTAL TAIL PRESSURE DRAG COEFFICIENT
.5        1.4       7.1       .04       .12389
.6        1.4       7.1       .039      .0905
END
```

TUESDAY, DEC 28, 1976

CIRCULAR ARC AIRFOIL - SECTION PRESSURE, FRICTION, AND TOTAL FORM DRAG COEFFICIENTS

SAMPLE CASE #1: VERTICAL TAIL - FORM DRAG COEFFICIENT

MACH = .50	GAM = 1.400	RE = .8100E+07	T/C = .0400	ATAIL/AREF = .1000	CDP = .00038	CDF = .00612	CDTOT = .00065
MACH = .60	GAM = 1.400	RE = .8100E+07	T/C = .0350	ATAIL/AREF = .3000	CDP = .00031	CDF = .00608	CDTOT = .00192
MACH = .70	GAM = 1.400	RE = .8100E+07	T/C = .0300	ATAIL/AREF = .5000	CDP = .00026	CDF = .00603	CDTOT = .00315
MACH = .80	GAM = 1.400	RE = .8100E+07	T/C = .0250	ATAIL/AREF = .7000	CDP = .00020	CDF = .00598	CDTOT = .00433
MACH = .90	GAM = 1.400	RE = .8100E+07	T/C = .0200	ATAIL/AREF = 1.0000	CDP = .00020	CDF = .00593	CDTOT = .00612
MACH = 1.00	GAM = 1.400	RE = .6900E+07	T/C = .0400	ATAIL/AREF = .1000	CDP = .01471	CDF = .00602	CDTOT = .00207
MACH = 1.10	GAM = 1.400	RE = .6900E+07	T/C = .0350	ATAIL/AREF = .3000	CDP = .01117	CDF = .00595	CDTOT = .00514
MACH = 1.20	GAM = 1.400	RE = .6900E+07	T/C = .0300	ATAIL/AREF = .5000	CDP = .00781	CDF = .00589	CDTOT = .00685
MACH = 1.30	GAM = 1.400	RE = .6900E+07	T/C = .0250	ATAIL/AREF = .7000	CDP = .00408	CDF = .00581	CDTOT = .00692
MACH = 1.40	GAM = 1.400	RE = .6900E+07	T/C = .0200	ATAIL/AREF = 1.0000	CDP = .00217	CDF = .00574	CDTOT = .00791
MACH = 1.50	GAM = 1.400	RE = .4900E+07	T/C = .0400	ATAIL/AREF = .1000	CDP = .00771	CDF = .00598	CDTOT = .00137
MACH = 1.60	GAM = 1.400	RE = .4900E+07	T/C = .0350	ATAIL/AREF = .3000	CDP = .00521	CDF = .00591	CDTOT = .00334
MACH = 1.70	GAM = 1.400	RE = .4900E+07	T/C = .0300	ATAIL/AREF = .5000	CDP = .00348	CDF = .00583	CDTOT = .00466
MACH = 1.80	GAM = 1.400	RE = .4900E+07	T/C = .0250	ATAIL/AREF = .7000	CDP = .00223	CDF = .00575	CDTOT = .00558
MACH = 1.90	GAM = 1.400	RE = .4900E+07	T/C = .0200	ATAIL/AREF = 1.0000	CDP = .00132	CDF = .00567	CDTOT = .00699
MACH = 2.00	GAM = 1.400	RE = .3500E+07	T/C = .0400	ATAIL/AREF = .1000	CDP = .00491	CDF = .00591	CDTOT = .00108
MACH = 2.10	GAM = 1.400	RE = .3500E+07	T/C = .0350	ATAIL/AREF = .3000	CDP = .00354	CDF = .00583	CDTOT = .00281
MACH = 2.20	GAM = 1.400	RE = .3500E+07	T/C = .0300	ATAIL/AREF = .5000	CDP = .00245	CDF = .00574	CDTOT = .00409
MACH = 2.30	GAM = 1.400	RE = .3500E+07	T/C = .0250	ATAIL/AREF = .7000	CDP = .00161	CDF = .00586	CDTOT = .00508
MACH = 2.40	GAM = 1.400	RE = .3500E+07	T/C = .0200	ATAIL/AREF = 1.0000	CDP = .00093	CDF = .00557	CDTOT = .00650
MACH = 2.50	GAM = 1.400	RE = .2000E+07	T/C = .0400	ATAIL/AREF = .1000	CDP = .00372	CDF = .00605	CDTOT = .00098
MACH = 2.60	GAM = 1.400	RE = .2000E+07	T/C = .0350	ATAIL/AREF = .3000	CDP = .00272	CDF = .00596	CDTOT = .00261
MACH = 2.70	GAM = 1.400	RE = .2000E+07	T/C = .0300	ATAIL/AREF = .5000	CDP = .00191	CDF = .00588	CDTOT = .00389
MACH = 2.80	GAM = 1.400	RE = .2000E+07	T/C = .0250	ATAIL/AREF = .7000	CDP = .00120	CDF = .00579	CDTOT = .00489
MACH = 2.90	GAM = 1.400	RE = .2000E+07	T/C = .0200	ATAIL/AREF = 1.0000	CDP = .00051	CDF = .00571	CDTOT = .00622

TUESDAY, DEC 28, 1976

CIRCULAR ARC AIRFOIL - SECTION PRESSURE, FRICTION, AND TOTAL FORM DRAG COEFFICIENTS

F-17 HORIZONTAL TAIL PRESSURE DRAG COEFFICIENT

MACH = .50	GAM = 1.400	RE = .7100E+07	T/C = .0400	ATAIL/AREF = .1239	CDP = .00039	CDF = .00625	CDTOT = .00082
MACH = .60	GAM = 1.400	RE = .7100E+07	T/C = .0380	ATAIL/AREF = .0985	CDP = .00039	CDF = .00621	CDTOT = .00065

APPENDIX B

COMPUTER LISTING

The listing provided herein includes the main program, subroutine spline and subroutine LDAY, which are currently operational on the NAVAIRDEVCEN CDC 6600 computer system.

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```
      PROGRAM SECTION(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
      DIMENSION X(50),Y(50),TITLE(8),Z(1),YINT(1),DYDX(1),SUMI(1)
     C,WHEN(3)
      DATA X/-10.,-8.,-7.,-6.,-5.5,-5.,-4.5,-4.,-3.5,-3.,-2.5,-2.,-1.5,-
     C1.,-.9,-.8,-.7,-.6,-.5,-.4,-.3,-.2,-.1,-.05,0,.1,.2,.3,.4,.5,.6,.
     C7,.8,1.,1.1,1.3,1.5,1.7,1.9,2.,2.1,2.5,3.,3.5,4.,4.5,5.,5.5,6.,7.,8./
      DATA Y/.065,.073,.078,.084,.088,.093,.098,.103,.108,.11,.122,.138,
     C.164,.327,.402,.536,.781,1.382,1.862,2.353,2.951,3.44,3.879,4.043,
     C4.209,4.389,4.433,4.368,4.297,4.28,4.275,4.264,4.257,4.25,4.245,4.
     C22,4.2,4.135,4.071,3.958,3.471,3.132,2.879,2.665,2.507,2.385,2.266
     C,2.177,2.078,1.888/
      CALL LDAY(WHEN)
      WRITE(6,9)
    9 FORMAT(1H1)
   10 FORMAT(1H),105X,3A10)
      L=3H999
      M=3HEND
      N=50
      MAX=1
    3 READ(5,1)(TITLE(I),I=1,8)
      WRITE(6,10) WHEN
      WRITE(6,5)
      J=1
    1 FORMAT(8A10)
    2 FORMAT(//,1X,8A10,//)
      WRITE(6,2)(TITLE(I),I=1,8)
    8 READ(5,4) XM,GAM,RE,TC,ATAR
      RE=RE*(10.**6)
    4 FORMAT(2F10.0,F10.4,2F10.0)
      Z(1)=(XM**2-1.)/((TC*(GAM+1.)*(XM**2))**(2./3.))
      CALL SPLINE(X,Y,N,Z,YINT,MAX,DYDX,SUMI)
      CDP=YINT(1)*(TC**(5./3.))/(((GAM+1.)*(XM**2))**(1./3.))
      CDF=((1.+.18*(XM**2))**(-.35))*((2.*.455)/((ALOG10(RE))**2.58))
      CDTOT=(CDP+CDF)*ATAR
    5 FORMAT(//25X,84H CIRCULAR ARC AIRFOIL - SECTION PRESSURE, FRICTION
     C, AND TOTAL FORM DRAG COEFFICIENTS//)
      IF(MOD(J,26).NE.0)GO TO 11
      WRITE(6,10) WHEN
      WRITE(6,2)(TITLE(I),I=1,8)
   11 WRITE(6,6) XM,GAM,RE,TC,ATAR,CDP,CDF,CDTOT
      J=J+1
    6 FORMAT(1X,7HMACH = ,F5.2,3X,6HGAM = ,F6.3,3X,5HRE = ,E10.4,3X,
     C6HT/C = ,F6.4,3X,13HATAIL/AREF = ,F6.4,3X,6HCDP = ,F7.5,3X,6HCDF =
     C ,F7.5,3X,8HCDTOT = ,F7.5)
      READ(5,7) ISWITCH
    7 FORMAT(A3)
      IF(ISWITCH.EQ.M) STOP
      IF(ISWITCH.EQ.L) GO TO 3
      BACKSPACE 5
      GO TO 8
      END
```



```
      SUBROUTINE SPLINE(X,Y,N,Z,YINT,MAX,DYDX,SUMI)
      DIMENSION X(1),Y(1),Z(1),DYDX(1),SUMI(1),YINT(1),D2YDX(50)
      DIMENSION A(50),B(50),C(50),EM(50),F(50),G(50),S(50),SB(50),W(50)
      IF(N.LE.1) RETURN
   10 DO 20 I=2,N
   20 S(I)=X(I)-X(I-1)
      NO=N-1
      IF(2.GT.NO) GO TO 40
      DO 30 I=2,NO
      A(I)=S(I)/6.0
      B(I)=(S(I)+S(I+1))/3.0
      C(I)=S(I+1)/6.0
   30 F(I)=((Y(I+1)-Y(I))/S(I+1))-((Y(I)-Y(I-1))/S(I))
   40 A(N)=-.5
      B(1)=1.0
      B(N)=1.0
      C(1)=-.5
      C(N)=1.0
      F(1)=0.0
      F(N)=0.0
      W(1)=B(1)
      SB(1)=C(1)/W(1)
      G(1)=0.0
      DO 50 I=2,N
      W(I)=B(I)-(A(I)*SB(I-1))
      SB(I)=C(I)/W(I)
   50 G(I)=(F(I)-(A(I)*G(I-1)))/W(I)
      EM(N)=G(N)
      DO 60 I=2,N
      K=N+1-I
   60 EM(K)=G(K)-(SB(K)*EM(K+1))
   80 DO 170 I=1,MAX
      K=2
      IF(Z(I)-X(1)) 150,90,120
   90 YINT(I)=Y(1)
      GO TO 160
  110 K=N
      GO TO 150
  120 IF(Z(I)-X(K)) 150,130,140
  130 YINT(I)=Y(K)
      GO TO 160
  140 K=K+1
      IF(K-N) 120,120,110
  150 YINT(I)=(EM(K-1)*((X(K)-Z(I))**3)/(6.*S(K)))+(EM(K)*((Z(I)-X(K-1))
     C**3)/(6.*S(K)))+(((Y(K)/S(K))-(EM(K)*S(K)/6.))*(Z(I)-X(K-1)))+(((Y
     C(K-1)/S(K))-(EM(K-1)*S(K)/6.))*(X(K)-Z(I)))
  160 DYDX(I)=-(EM(K-1)*((X(K)-Z(I))**2)/(2.*S(K)))+(EM(K)*((X(K-1)-Z(I)
     C)**2)/(2.*S(K)))+((Y(K)-Y(K-1))/S(K))-((EM(K)-EM(K-1))*S(K)/6.)
      D2YDX(I)=(EM(K-1)*(X(K)-Z(I))/S(K))+(EM(K)*(Z(I)-X(K-1))/S(K))
  170 CONTINUE
      IF(MAX.LE.1) RETURN
      SUM2=0.
      DO 190 I=2,MAX
      SUM1=SUM2
      SUM2=.5*(Z(I)-Z(I-1))
      SUM2=SUM1+ABS(SUM2*((YINT(I-1)+YINT(I))+.4*SUM2*((DYDX(I-1)-DYDX(I
     C))+(SUM2/6.)*(D2YDX(I-1)+D2YDX(I)))))
  190 SUMI(I-1)=SUM1
      SUMI(MAX)=SUM2
      RETURN
```

```
      END
```

```
      SUBROUTINE LDAY(MDAY)
      DIMENSION MDAY(3), LONG(7), MONTH(12),IBREV(7)
      DATA MONTH / 5H  MAR, 5H  APR, 5H  MAY, 5H  JUN, 5H  JUL, 5H  AUG,
     1 5H  SEP, 5H  OCT, 5H  NOV, 5H  DEC, 5H  JAN, 5H  FEB/
      DATA LONG / 10H    SUNDAY,,10H    MONDAY,,10H   TUESDAY,,
     1 10HWEDNESDAY,,10H THURSDAY,,10H    FRIDAY,,10H SATURDAY,/
      DATA IBREV / 10H       SUN,,10H       MON,,10H       TUE,,
     1 10H       WED,,10H       THU,,10H       FRI,,10H       SAT,/
    1 FORMAT(3(1XI2))
    2 FORMAT(A6,I2,4H, 19,I2)
    3 FORMAT(I4)
      I = 3
      GO TO 4
      ENTRY SDAY
      I = 1
    4 CALL DATE(DAY)
      DECODE(10,1,DAY)IY,IM,ID
      IA = IM
      IF( ID.LE.31 ) GO TO 5
      IM = IY
      IY = ID
      ID = IA
    5 IM = IM + 10
      IF( IM.GT.12 ) IM = IM - 12
      ENCODE(20,2,MDAY(2))MONTH(IM),ID,IY
      DECODE(10,3,MDAY(3))NYEAR
      IF( IM.GE.11 ) NYEAR = NYEAR - 1
      NC = NYEAR/100
      ND = NYEAR - 100*NC
      IC = 2.59 * FLOAT( IM )
      IC = IC + NG/4
      IC = MOD(IC + ID - NC - NC + ND + NC/4,7)
      IF( IC.LT.0 ) IC = IC + 7
      IF( I - 1 ) 7, 7, 6
    6 MDAY(1) = LONG( IC+1 )
      RETURN
    7 MDAY(1) = IBREV ( IC+1 )
      RETURN
      END
```

APPENDIX C

COMPUTER PROGRAM USER'S GUIDE

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O P E R A T I N G   I N S T R U C T I O N S

The program input data requirements are specified in Table 1, where a minimum of three data cards are required for execution. The first data card is reserved for input of an alphanumeric case identification title in columns one through eighty.

The second card contains the airfoil geometric and flight parameters in the following format; the free-stream Mach number (XM) is input in the first ten columns, the specific heat ratio (GAM) is input in columns 11 through 20, the airfoil Reynolds number (RE) is input in columns 21 through 30, the airfoil thickness to chord ratio (TC) is input in columns 31 through 40, and the airfoil surface area to reference area ratio (ATAR) is input in columns 41 through 50. The data supplied on card number 2 is sufficient for the program to calculate the required drag coefficient values associated with the input data. Additional input data with the same case identification title can be supplied, as necessary, by repeating the card 2 input format for each set of additional input data.

The case input data can be terminated using the third type of input card listed in Table 1 with parameter ISWITCH set equal to "END" in columns 1 through 3, or a new case with associated identification title can be initiated by setting ISWITCH equal to 999. Additional input case data can then be entered following the input specifications of cards 1 through 3.

The output format consists of the following information; the case title is printed as a header in the form specified on input card 1, the five input parameters from card 2 are then printed followed by the calculated values of pressure drag and friction drag coefficients based on airfoil surface area followed by the total form drag coefficient based on the drag reference area.

TABLE 1

PROGRAM INPUT DATA FORMAT

Card	Quantity	Mode	Columns	Description
1	Title	Alphanumeric	1-80	Case Identification Title
2	XM	Real	1-10	Free-stream Mach number
	GAM	Real	11-20	Ratio of specific heats
	RE	Real	21-30	Reynolds number (in millions)
	TC	Real	31-40	Airfoil thickness to chord ratio
	ATAR	Real	41-50	Airfoil surface area to reference area ratio

Repeat card number 2 format, as necessary, for additional input data.

Card	Quantity	Mode	Columns	Description
3	ISWITCH	Alphanumeric	1-3	For end of data; ISWITCH = END For new case; ISWITCH = 999, the enter card 1 and 2 format for additional data.